FARMERS' BULLETIN 1248
UNITED STATES DEPARTMENT OF AGRICULTURE

The SUGAR-BEET NEMATODE *in the* WESTERN STATES

THE SUGAR-BEET NEMATODE is one of the most serious of the beet pests. It appears to have been imported with some shipments of beet seed many years ago. It has been found widely scattered in four of the western sugar-beet States and probably exists in other States where beets have been grown for several years.

The sugar-beet nematode is the cause of a great deal of loss to the beet grower through reduction of his tonnage, and of a corresponding amount of loss to the sugar producer through reduction of the output of sugar.

This bulletin treats of the nature and distribution of the sugar-beet nematode, indicates the most probable means by which this pest is spread, and suggests preventive measures and practical means of control.

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief
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THE SUGAR-BEET NEMATODE IN THE WESTERN STATES.

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HISTORY AND DISTRIBUTION OF THE SUGAR-BEET NEMATODE.

THE SUGAR-BEET NEMATODE[1] has infested many of the principal beet-growing regions of Europe, where it has become one of the most serious pests of the sugar beet and has caused severe losses.

It was first found in the sugar-beet fields of the western United States about 15 years ago. Since that time it has been found in many of the principal beet-growing sections of Utah, Idaho, California, and Colorado. Representatives of the Office of Sugar-Plant Investigations have made complete or partial surveys of all these regions except northern Colorado.

Surveys of nematode-infested areas in Utah were begun in 1919 and have been continued up to the present time. Franklin County, Idaho, was surveyed in 1918 and 1919. In 1920 the work was extended to include the Oxnard, Betteravia, Salinas, and Alvarado districts in California and the Arkansas Valley in Colorado.[2] The areas surveyed in four different States and the acreage found infested were as follows:

Utah, area surveyed, 24,473 acres, area infested, 3,238 acres; Idaho, area surveyed, 2,096 acres, area infested, 515 acres; Colorado, area surveyed, 7,160 acres, area infested, 899 acres; California, area sur-

[1] *Heterodera schachtii* Schmidt.

[2] Acknowledgment is due to Dr. E. G. Titus, under whose direction this work was begun, and to Charles Price, George Q. Bateman, T. L. Smart, and E. W. Newman for their faithful work in the field.

veyed, 18,945 acres, area infested, 2,535 acres; total area surveyed, 52,674 acres; total area infested, 7,187 acres. In reporting the infested acreage the total areas of infested fields were given. Since the actual infested areas vary from a few square rods to the entire field it will be conservative to figure the actual infested area as 25 per cent, or 1,797 acres. The average loss because of the infestation in these States may be estimated at not less than 6 tons of beets per acre, or 10,762 tons. Valued at $12 per ton, the prevailing price in 1920, the cash loss to the growers alone was $129,124.

The results of these surveys show that the infestation is spreading rapidly and in some localities has become a serious menace to the sugar-beet industry. The map shown as figure 1 gives the distribu-

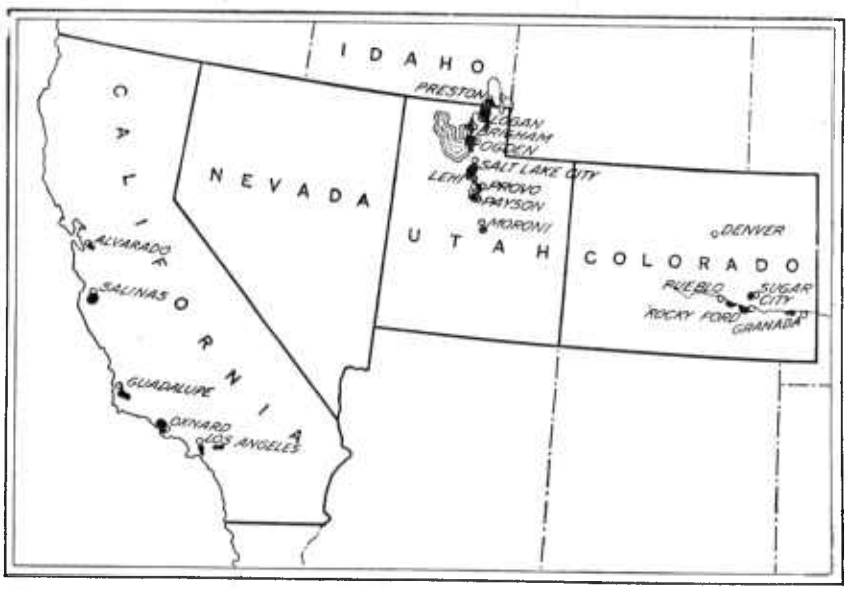

FIG. 1.—Outline map of four western beet-growing States, showing (by dark areas) where the sugar-beet nematode has been found.

tion of this nematode in the United States, as it is known at the present time. It should be noted that only about one-twentieth of the sugar-beet acreage in the United States has been inspected for the nematode, and it is probable that many additional infested fields will be found when a careful inspection of the other areas is made.

LIFE HISTORY OF THE NEMATODE.

The forms of the sugar-beet nematode that are visible to the unaided eye are the females and brown cysts, which are about one-fourth the size of an ordinary pinhead. Practically speaking, these

forms are masses of 200 to 600 nematode eggs. (Fig. 2.) These eggs are about one three-hundredth of an inch long and one-half as thick. (Fig. 3.) From them hatch very small, almost colorless, threadlike larvæ, which average one-sixtieth of an inch long. (Fig. 4.) They are equipped with a strong spear (fig. 5), with which they force an opening so that they can enter the roots of the beet, where they feed on the plant juices and molt.

FIG. 2.—Cyst form of the sugar-beet nematode which has been crushed in order to show the eggs and larvæ. This cyst was taken from a field that had not been planted to beets for two years. × 20. Photographed by Gerald Thorne.

Up to the time of molting there is no visible difference between the sexes, but afterwards there is little similarity. The males remain similar to the larvæ except that they are somewhat larger and that their tails are blunt and their spears stronger. (Fig. 6.) After maturing they break their way from the roots and go in search of the females.

After molting the second time the females are flask shaped. As their size increases they break through the beet tissues and remain attached by their heads. Here they are fertilized by the males and soon develop into lemon-shaped bodies. A gelatinous semitransparent fluid is excreted, which collects in a mass about the posterior end, often filling the space between the female and the beet root. Into this mass eggs are deposited and there hatch, the larvæ finding their way into the soil or into the beet. The number of eggs deposited varies from a few to upward of a hundred from each female, and since several generations occur there are enormous numbers infesting the beet by the end of the season.

FIG. 3.—Eggs of the sugar-beet nematode from a brown cyst. × 100. Photographed by Gerald Thorne.

As the season advances many of the females change in color from white to dark brown, becoming what is commonly known as the brown-cyst or preservation form. In this form the dead body of the female remains a protecting sack for the eggs with which she was filled, and in it they may lie dormant

for many years. Just how long is not known. Each year, when favorable soil and moisture conditions occur, a few of these eggs hatch. The larvæ escape from the cyst either through the anal opening or through the opening left when the female broke loose from the beet root. (Fig. 7.) This leaves the cyst intact and a protecting cover to the eggs remaining within it.

FIG. 4.—Larvæ of the sugar-beet nematode just hatched from the eggs. Note the sharp tails. × 150. Photographed by Gerald Thorne.

HOW THE LIFE HISTORY WAS STUDIED.

The life history and habits of the sugar-beet nematodes were studied in the laboratory to see if something might be learned that would suggest possible means of control. The depth at which they could be found in the soil, the depth at which they were found in the greatest abundance, the time when new cysts began to appear, and the possible succession of broods at more or less regular intervals were points kept constantly in mind.

For this work three fields were selected in 1919 and four in 1920. From these fields soil samples were taken at frequent intervals for examination. The soil in all these fields was a sandy loam, though there was a slight variation in the different fields, some having a deeper and looser soil than others. On the whole, the soil of these fields was typical of the region under investigation (Salt Lake County, Utah). From these fields 128 samples were taken and examined. From these samples 114,566 white females and 94,312 brown cysts were obtained. No attempt was made to obtain a count of the males and larvæ, owing to the fact that they are so small that they can be seen only with a microscope, and any method of separating them from the soil would be very slow and laborious. By determining the numbers of females and brown

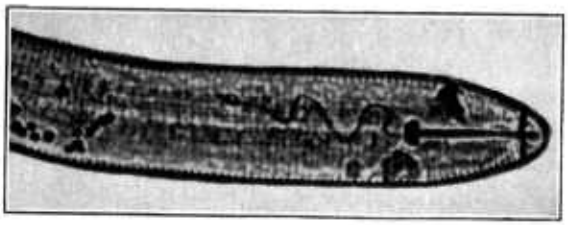

FIG. 5.—Head of the larva of the sugar-beet nematode, showing the spear with which it works its way into the beet root. × 1,000. Photographed by Gerald Thorne.

cysts a probable approximation of the comparative numbers of nematodes at various depths in the soil was obtained. These numbers no doubt represent only a small part of the males, larvæ, and undeveloped females that were actually in the beets and the soil surrounding them.

The samples were taken with soil tubes 6 inches in length and having an internal diameter of 2.84 inches, or a cross-sectional area of one-millionth of an acre. If the beet was small its top was removed, and the tube was placed over it and pressed down to its full length. Later in the season the tube was pressed down by the side of the beet, so as to include as much as possible of the root system on one side of the plant. It was then dug out, care being taken to cut the roots at the bottom of the tube, so as not to pull out any of the soil in lifting the tube. The second tube was then set in the place from which the first had been removed, pressed down, and removed in the same manner as the first tube. Five tubes, reaching to a depth of 30 inches, were successively used in taking many of the samples.

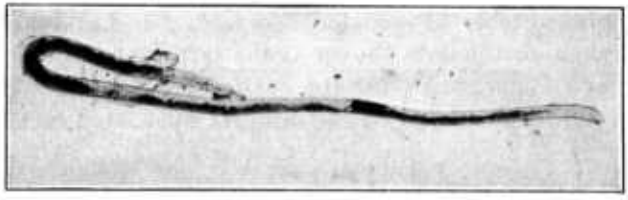

FIG. 6.—Adult male of the sugar-beet nematode. Compare with figure 4. Photographed by Gerald Thorne.

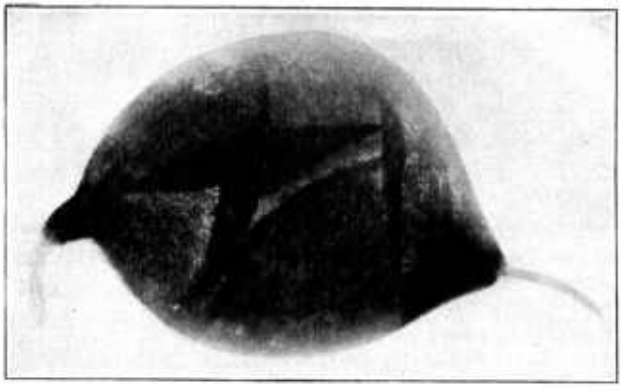

FIG. 7.—Larvæ of the sugar-beet nematode emerging from a brown cyst. The cyst remains intact and forms a protection to the eggs and larvæ yet remaining in it. × 100. Photographed by Gerald Thorne.

In examining these samples each 2 inches of soil was washed and examined by itself. The soil to be washed was placed in a pan filled with water and thoroughly worked with the hands to break up all clods. The whole was then stirred and poured off through a sieve having 40 meshes to the inch. More water was added to the material remaining in the pan, and the pouring process was continued until only the coarsest material was left in the pan. The finer material passed through the screen, and the nematodes lodged in the sieve together with the medium-sized material. This

method of washing collected the females and the cysts but not the larvæ and the males. The material remaining on the screen was then examined and the nematodes counted.

After the samples had been examined and the counts made, tables were prepared showing the results obtained from each field for the entire season. One of these tables, that for field No. 2, examined in 1919, is here given, being typical of the results obtained from the seven fields under investigation. The table is arranged to show the total number of nematodes in each 2 inches of soil from the sample taken on the date shown at the left. At the right is the total number of nematodes for the entire sample, and at the bottom are the total numbers for all the samples for each 2 inches in depth.

Nematode counts, field No. 2, examined in 1919.

Date.	Depth in inches (number of nematodes found).															
	1 to 2	3 to 4	5 to 6	7 to 8	9 to 10	11 to 12	13 to 14	15 to 16	17 to 18	19 to 20	21 to 22	23 to 24	25 to 26	27 to 28	29 to 30	Total.
July:																
7	3	85	198	33	4	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	325
18	6	41	86	18	4	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	156
23	45	245	123	6	0	0	0	0	0	.....	.....	.....	.....	.....	.....	421
29	2	8	47	24	15	25	2	0	0	.....	.....	.....	.....	.....	.....	123
31	9	59	93	17	5	3	0	1	0	.....	.....	.....	.....	.....	.....	187
August:																
1	62	202	302	21	6	2	4	1	13	.....	.....	.....	.....	.....	.....	613
4	8	67	142	36	9	12	17	13	8	1	0	.....	.....	.....	.....	313
5	7	202	351	137	86	28	5	2	0	.....	.....	.....	.....	.....	.....	818
7	21	96	318	191	52	16	11	2	3	.....	.....	.....	.....	.....	.....	710
9	43	264	717	249	193	16	11	10	8	.....	.....	.....	.....	.....	.....	1,511
14	195	251	502	276	178	39	5	0	0	.....	.....	.....	.....	.....	.....	1,446
19	187	610	478	307	223	73	11	10	3	.....	.....	.....	.....	.....	.....	2,002
20	261	1,140	905	334	96	38	5	3	2	.....	.....	.....	.....	.....	.....	2,784
21	213	464	2,112	865	760	265	197	91	60	.....	.....	.....	.....	.....	.....	5,027
30	155	1,813	2,077	1,234	164	287	12	8	5	.....	.....	.....	.....	.....	.....	5,555
September:																
5	58	627	132	730	385	255	121	57	90	58	65	.....	.....	.....	.....	2,579
13	268	4,125	5,718	2,292	1,157	534	307	108	82	65	33	6	4	0	0	14,699
20	515	1,679	5,033	1,180	391	294	171	121	92	69	54	39	23	12	5	9,611
27	574	2,389	3,727	1,184	325	244	92	(a)	15	27	15	10	3	21	1	8,608
October:																
12	679	3,154	2,770	833	261	48	21	29	19	13	8	5	19	18	5	7,842
November:																
1	707	3,532	1,713	472	178	30	21	31	33	33	14	8	1	0	0	6,840
22	986	1,489	559	105	23	12	36	6	2	.....	.....	.....	.....	.....	.....	.....
Total	5,004	22,542	28,103	10,644	4,517	1,952	1,116	493	435	226	190	68	53	32	11	75,426

a Sample lost.

The greater number of nematodes are found in the first few inches of soil, but what is of equal or even greater importance is the fact that they are found at a depth of 30 inches, and if samples had been taken at greater depths it is possible that infestation might have been found below 30 inches. The greatest number of nematodes for any 2 inches was found in the third 2 inches. The results obtained from the other fields correspond very closely with those given for field No. 2.

From a consideration of the results obtained from the seven fields from which samples were taken, it seems that control of nematodes attacking the sugar beet must depend chiefly on cultural methods and crop rotations. The data obtained did not indicate any definite succession of broods of the nematode. Much of the infestation seemed to come from cysts of former years which were found throughout the summer loose in the soil. The first cysts which were attached to the roots of the beet, and therefore were considered new cysts, were found on June 28. During the summer of 1920, soil

FIG. 8.—Sugar-beet field near Lewiston, Utah, containing a small area very severely infested with nematodes. Photographed by Gerald Thorne.

samples were taken at different times between the rows of beets. In these samples great numbers of brown cysts were found, containing eggs and larvæ, but no females were found in the samples, probably owing to the absence of food plants necessary for their development.

HOW TO DETERMINE NEMATODE INFESTATION.

The first symptom of nematode injury is the appearance of small areas in the field which produce no beets or only a few undersized ones. (Fig. 8.) Unless a considerable quantity of infested soil has been hauled into the field it is usually two or three years after infestation before the areas are large enough to attract attention. On severely infested areas the beets wilt and wither away just after thinning, often only a few remaining. These do not make as rapid

growth as those outside the infested soil. If the infestation is only slight or moderate and the moisture and cultural conditions favorable for growth, the beets do not die but are smaller than those surrounding them. As the season advances these will be found to wilt down much more readily on warm days.

If one of these infested beets be carefully dug up, it will be found small and stunted, with many more small roots than the normal beet. (Fig. 9.) In some instances the entire taproot is covered with these small roots, many of them being brown and dead. If nematodes are present, an examination will usually reveal small lemon-shaped white bodies clinging to the roots. These are the female form of the nematode. Later in the season these bodies are found on the beet itself, more than 100 to the square inch not being unusual. At this time it will probably be noticed that many of them are becoming brown in color. These visible forms of the nematode are not able to move at all, and the beginner should be careful not to confuse them with the sugar-beet aphis,[3] which is a true insect several times as large as the nematode and which can be seen to move slowly about. These aphids are commonly found in dry spots in the field where the beets resemble somewhat those infested with nematodes.

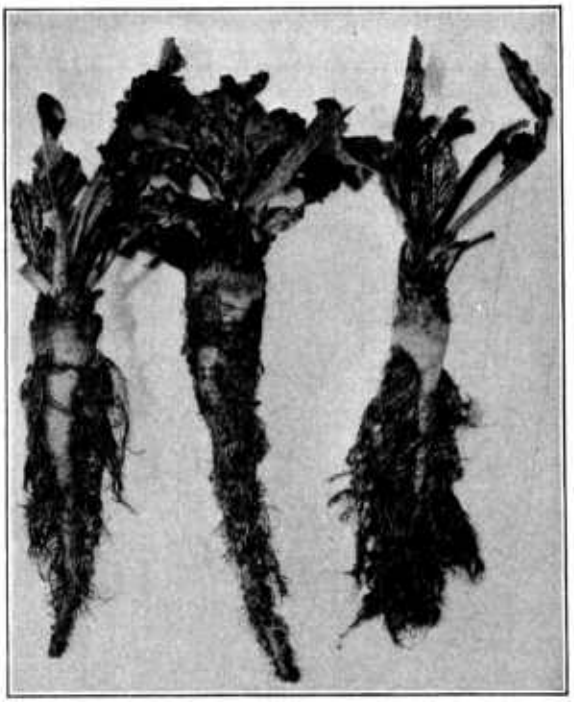

FIG. 9.—Beets from a field in which the crop was a complete failure because of severe nematode infestation. About one-third actual size. Photographed by Gerald Thorne.

Other causes which produce an appearance similar to that of nematode injury are alkali spots in the soil, the garden or root-knot nematode, excessive moisture, and dry spots. In fact it is absolutely necessary to make a careful examination of the beet roots and to find the nematodes before their presence is known for a certainty.

[3] *Pemphigus betae.*

Beets infested with nematodes appear to be more susceptible to leaf-spot, Phoma, and other leaf diseases, because of their weakened condition. For this reason diseases are sometimes assumed to be the cause of inferior growth when the actual primary cause is that of nematodes robbing the beet of its food. In the Arkansas Valley, Colo., the presence of small areas of leaf-spot in the fields was often found to be associated with nematodes, and because of the leaf-spot the infestation had been overlooked for several years.

At times it is very difficult to find the nematodes on the beets even in severely infested fields. This condition usually prevails in fields that are very dry, the nematodes having died from lack of moisture. The white females require considerable moisture and wither away to tiny white scales when dried. Careful examination of such fields will usually locate some of the brown cysts either attached to the roots or in the soil surrounding them.

One of the surest methods of determining whether the soil is infested is to put a few handfuls in a bucket of water and stir thoroughly. Many of the cysts, especially those from which part of the larvæ have emerged, will float on the top of the foam and collect around the side of the bucket. They resemble small brown seeds and will probably be mixed with some seeds that are slightly similar, from which they can be distinguished, however, by the fact that the seeds are larger and hard, while the cyst can be easily crushed. For one not accustomed to their appearance it may be difficult to be certain of them, and a small hand lens will be of service in identification. In case of doubt send a few pounds of soil to the office of Sugar Plant Investigations of the Bureau of Plant Industry, United States Department of Agriculture, Salt Lake City, Utah. It will be carefully examined, and if nematodes are present they will usually be found. This service is free of charge.

HOW THE SOIL BECOMES INFESTED.

The first nematodes probably reached the United States from Europe, being carried in sugar-beet seed. This is probable, because when beet seed is grown on land infested with sugar-beet nematodes, small clods of soil, which are often mixed with the seed, would be very likely to contain some of the brown cysts, and these would be planted with the seed. Since the infested areas are in many instances far apart, shipments containing infested soil must have been received in many localities.

After becoming established in a field the nematodes are spread over it in many ways. Cultural implements, especially cultivators, levelers, and harrows, drag particles of soil containing the nematodes from the infested area and scatter them in other parts of the field.

Irrigation water running over infested soil picks up the cysts and deposits them along the furrows, where new colonies are soon established. Live stock tramping over a wet field may carry cysts in the mud on their feet and thus distribute them to other parts of the field. It is doubtful whether the natural migration of the nematodes themselves will carry them more than a rod in a season, and therefore these other agencies are those which should be considered in preventing its spread. It is often found that the infested area in a field is only 3 or 4 rods wide and several times as long, following the course of irrigation and cultivation. (Fig. 10.)

FIG. 10.—Sugar-beet field near Preston, Idaho, showing a nematode-infested area averaging 3 rods wide and more than 20 rods long, following the course of irrigation and cultivation. Photographed by Gerald Thorne.

From farm to farm the nematodes are carried by machinery, live stock, irrigation water, and any other methods that will transport the infested soil from one place to another. The common custom of farmers receiving back into their wagons the dirt from the beets which they have delivered at the unloading station, is probably the most serious method of distribution. Some of the soil from infested beets sticks to the dump screens, is jarred loose by the load of beets next following, and finds its way into the wagons of other farmers. In this way the farmers receive infested soil, take it to their fields and often scatter it, thinking that this good rich soil should not be lost. Fortunately this practice is becoming less common, and the

dirt is disposed of before reaching home, but this is usually done along the road where wagon wheels and the feet of horses may pick it up and carry it into the fields.

CONTROL METHODS.

Dirt from the beet dumps apparently being the most common means of spreading the infestation, it should be the first to receive attention in planning control methods. Since the removal of dirt from the dumps seems to be the only practical method of disposing of the thousands of tons of soil annually screened from the beets, precautions must be taken to prevent scattering the soil containing nematodes. Wagon boxes should be tight enough to prevent soil jarring out along the roads and in the fields. Dump dirt should be disposed of in holes, swamps, or waste corners where there is the least danger of its being scattered.

The practice of growing beets year after year on the same field gives the nematodes an excellent opportunity to become established if they are introduced. A definite system of crop rotation should be adopted with not more than two years of beets in succession. The fertility of the soil will thus be maintained, and much of the danger from insect pests and plant diseases will be avoided at the same time.

When nematodes are found in a locality, action should immediately be taken to prevent their spread. This should be made a community affair, and the following measures are being adopted by some of the farm bureaus:

(1) The sugar company operating in the district is requested to refuse contracts for beets grown on soil that is known to be infested with the sugar-beet nematodes.

(2) When infested soil happens to be planted the owner and the sugar company are to make arrangements for handling the beets from the infested areas separately and not allow the infested beets to go through the dumps while other beets are being handled.

(3) The practice of throwing dump dirt along public highways is to be prohibited, by law if necessary.

After the extremely serious nature of the pest is realized there should be no difficulty in organizing such a cooperative campaign. The owner of infested soil should not desire to raise beets when the crop is likely to be a failure. The sugar company should not care to receive nematode-infested beets, which are low in sugar content, usually averaging about 10 to 12 per cent.

After the sugar-beet nematode has once become established in a field it is very doubtful whether it can ever be eradicated by employing methods that are applicable to field conditions. Experiments have demonstrated the fact that the nematodes live and reproduce in the soil to a depth of at least 2½ feet, and there are reports of their living deeper than this in warm climates. While protected by the

cyst, the eggs are not injured by drying at the ordinary field temperatures. It is also impossible to drown them, since cysts submerged in water for several weeks contain all the eggs undamaged. Treating the infested areas with lime and other chemicals has been recommended, but considering the depth to which the nematodes live it is obviously out of the question to do this. While quicklime and some other chemicals kill all the nematodes with which they come in contact there are almost certain to be some which they can not reach.

Crop rotation and cultural methods must then be considered as the only practical methods of control that are available. The following information is based on the results of observations on several hundred infested fields under actual cultural conditions.

Moderately or slightly infested fields often can be made to produce good crops of beets by planting the seed at a time when it will sprout immediately and the small beets make rapid growth. In growing beets under these conditions it is necessary to have irrigation water available to apply whenever needed and thus keep the beets growing thriftily. Infested soil will require much more water than uninfested soil, for it is the moisture content of the beet carrying the plant food which the nematodes take. To supply this extra plant food the soil must be well fertilized and cultivated. Early planting is of advantage, provided irrigation water is available. If beets are allowed to want for water during the growing season there is very little likelihood of their recovering sufficiently from the nematode attacks to produce a profitable crop. Where rainfall must be depended upon it is very doubtful whether it would pay to attempt to produce beets on even slightly infested soil.

Severely infested fields will require a crop rotation to reduce the nematode population of the soil and also to put the soil in better condition. Since the brown-cyst form allows the nematode to lie dormant in the soil for several years, the rotation should cover not less than three years, and a longer period would be preferable. During this time a large number of the larvæ will have hatched and emerged from the cysts, and these will die if no suitable food plants are available.

The subject of food plants is an important one in planning the rotation. Fortunately, all the common crops, including wheat, oats, corn, barley, potatoes, peas, beans, alfalfa, and the clovers, are not injured by the sugar-beet nematode. In certain localities some varieties of these crops may be host plants, but observations made on many severely infested fields have never shown the sugar-beet nematode on any in the above list. In fact, it is very common for these crops to make a larger growth on the severely infested areas. This is explained by the fact that these areas have produced no crop while planted to beets and yet have received cultivation and care

equivalent to a good summer fallow. The only cultivated crops found by the writers to be injured are cabbage, cauliflower, turnips, table beets, and mangels. However, the sugar-beet nematode is known to thrive on certain weeds, among them being mustard, pigweed (lamb's-quarters), and saltweed. A few are sometimes found on knotweed, redroot, and purslane. Clean seed and clean culture will therefore be essential if any good results are to be gained in making the rotation.

The shortest crop rotation that has given a good crop of beets on severely infested soil is one or two years of either peas or beans. By keeping the beets growing thriftily it is possible to harvest a good crop after this short rotation, but no attempt should be made to grow a second crop, as it almost invariably fails.

Another apparently successful rotation is as follows: Wheat or oats as a nurse crop for alfalfa. The following spring allow the alfalfa to grow about 1 foot high; then plow under and plant potatoes. The next year grow beets, and then repeat the rotation.

A rotation of three or four years of grain, potatoes, or other nonleguminous crops seldom gives a good crop of beets and should not be depended upon if a legume crop can possibly be grown.

Complete eradication of the sugar-beet nematode by a long crop rotation may be possible, but the following records of nematode-infested fields show that it is a very difficult thing to do:

(1) Alfalfa nine years. Soil still contains thousands of cysts and many of them have many eggs remaining in them in which the larvæ are alive and active.

(2) Wheat as a nurse crop for alfalfa, alfalfa four years, potatoes two years, beets (26 tons per acre), beets (11 tons) very severely infested with nematodes.

(3) Wheat as a nurse crop for alfalfa, alfalfa five years, wheat, beets (12 tons, allowed to get dry in July and never recovered), beets (11 tons) very severely infested again.

(4) Wheat, barley, alfalfa five years, wheat, wheat, beets (18½ tons, but so severely infested that the owner will not risk another crop).

(5) Mixed-grass pasture five years, wheat, wheat, beets (16½ tons), beets (9 tons very severely infested).

All of the fields mentioned above were under good farming practice, and the number of weeds growing in any one of them was probably no greater than would be found in any field in which an effort was being made to keep it clean. It will be noted that even these long crop rotations gave only one good crop of beets. Therefore the shorter rotations seem to be about equal so far as the beet crop is concerned, but the longer rotations should be used if possible, as the continual production of crops of only one or two kinds will in time deplete the soil of some of its important elements.

Remember that the nematode is a worm and must be carried into a field in order to get there. Beets may be grown in a field indefinitely, and no nematode will appear if it is not carried there. As mentioned before, there may be a slight possibility of its being carried in beet seed, but the most common means of distribution from field to field is through the dump dirt and the exchange of machinery which has been used on infested land. If such machinery is carefully cleaned after being used there is little probability that nematodes will be carried in this manner. By taking the precautions heretofore mentioned there is little danger of getting the soil infested with the sugar-beet nematode. And since it injures practically none of the other common crops there is no reason for hesitating to grow beets.